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Alcala, Lucia R.; Lei, Anders; Thomsen, Erik Vilain

Publication date:
2016

Document Version
Peer reviewed version

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Citation (APA):
Alcala, L. R., Lei, A., & Thomsen, E. V. (2016). *Finite Element Modelling of a Magneto Elastic Broadband Energy Harvester*. Abstract from 42nd International conference on Micro and Nano Engineering, Vienna, Austria.

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Finite Element Modelling of a Magneto Elastic Broadband Energy Harvester

L. R. Alcalá^a, A. Lei^a, E.V. Thomsen^a

^a Technical University of Denmark (DTU), Lyngby, 2800, Denmark
e-mail: lucala@nanotech.dtu.dk

Keywords: vibrational energy harvester, broadband, non-linear, FEM simulation, multi-stable, bi-stable.

Small-scale vibrational energy harvesters (VEH) to power wearable devices and wireless sensors have recently received considerable interest [1-4]. Two main challenges for VEHs are the low frequency bandwidth and keeping the resonance frequency sufficiently low to harvest energy from ambient vibrations. One of the most common approaches to enhance the frequency bandwidth is to use a cantilever structure and introduce one or two permanent magnets on the outside and either a permanent magnet or a ferromagnetic material on the cantilever's tip [2,3], resulting in a non-linear VEH that can exhibit either a monostable or a multistable response.

The objective of this work is to develop cantilever-based broadband magneto elastic energy harvesters with lateral dimensions below one centimeter and vertical dimensions smaller than 3 mm for powering autonomous wireless measurement systems. A side-view sketch of the system is shown in Fig. 1, and the chosen dimensions are listed in Table 1. Small permanent magnets are placed close to the tip of silicon cantilever in either a North-North (N-N) or North-South (N-S) configuration. The cantilever has integrated iron foils. The magnet separation parameters a and b are varied in the range of realistic values that would allow to realize miniaturized broadband energy harvesters. This is achieved by finite element modeling (FEM), which is an important tool for efficient design and optimization of piezoelectric vibrational energy harvesters [1].

The multi-physics FEM studies were performed in COMSOL 5.2 combining the Solid Mechanics and the Magnetic Fields modules. The simulation has two steps. First, an external force is applied and the tip displacement is calculated. Then the magnetic force is found. This allows finding the total force and the potential energy. The simulations were performed for both the N-N and N-S configurations to determine the most suitable configuration.

Fig. 2 shows the calculated potential energy for a cantilever without any magnetic force and for a N-N configuration. As expected, for the N-N configuration three different potential energy landscapes can be identified: 1) monostable, 2) a "flat" potential and 3) a bistable configuration. The flat potential corresponds to having an effective spring constant close to zero. This means that larger deflections can be achieved and at the same time a much broader range of frequencies can be harvested. This is a suitable configuration for a broadband VEH. The bistable case can also be used for a broadband EH. However, a potential well is formed, this means that in order to obtain large deflections the cantilever must have enough energy to overcome this well, which is not optimal for harvesting energy from ambient vibrations.

Fig. 3 shows the combinations of the a and b values required to obtain a flat potential for both the N-N (blue) and N-S (red) magnet configurations. It can be seen that the N-N configuration allows a smaller value of a for any separation between the magnets, which could be an advantage for a miniaturized system and due to the curvature of the line it will be easier to adjust a and b to obtain a flat potential energy landscape. The N-S configuration allows for larger values of a and b that could be easier to obtain in practice although the requirements to the positioning accuracy are higher as the contour line is very steep.

In conclusion, a FEM capable of finding the optimized dimensional parameters for a broadband magneto elastic VEH has been developed. It has been shown that the magnetization configuration for the external magnets leads to different optimal parameters, and the N-N configuration is found to be the most suitable configuration for miniaturized broadband EH.

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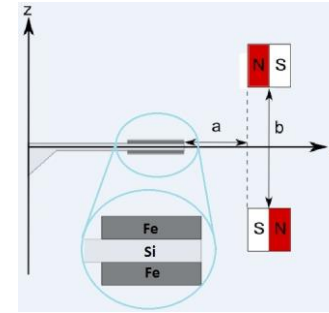


Figure 1. Side view of the vibrational system with a N-S magnetic set-up. The silicon cantilever has integrated iron foils.

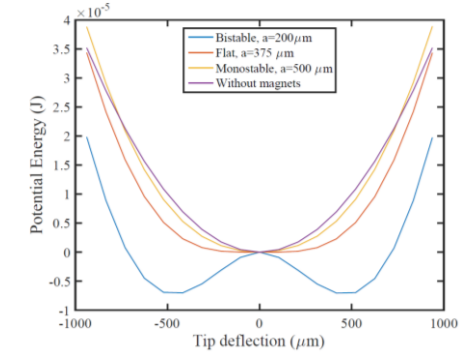


Figure 2. Potential energy for a system without magnets and for $b=500 \mu\text{m}$ with three different values for the distance between the cantilever tip and magnets: $a=200 \mu\text{m}$, $370 \mu\text{m}$ and $500 \mu\text{m}$.

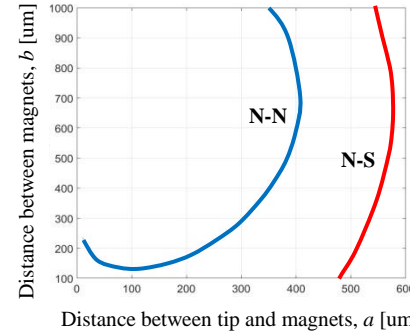


Figure 3. The contour lines show magnet separation parameters a and b for which the potential is flat for both the N-N (blue) and N-S (red) magnet configuration.

Device parameters	Values
Beam length	6.5 mm
Beam thickness	40 μm
Foil length	3.25 mm
Foil thickness	150 μm
Magnet length	1 mm
Magnet thickness	1 mm
Magnetization	750 kA/m

Table 1. Dimensional parameters used for the simulations.